Pharmacy Education (2025) 25(1) 42 - 52
https://doi.org/10.46542/pe.2025.251.4252

RESEARCH ARTICLE

Fostering student agency and confidence through problem-based learning and cognitive reflection in the pharmaceutics laboratory

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Keywords
Cognitive reflection
Drug compounding
Laboratory teaching
Problem-based learning

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Abstract

Background: Pharmaceutics is a pivotal subject in pharmacy education, and among the learning outcomes of pharmaceutics laboratory courses is the ability to instil practical skills in compounding, with a focus on quality control. Student feedback reveals that strict passing criteria cause apprehension, ultimately acting as barriers to learning. **Objective:** To foster meaningful learning, increase student confidence, and promote student agency through problem-based learning in the pharmaceutics course at the University of Bergen. **Method:** The three-part educational intervention included a pre-lab workshop, practical laboratory work, and a post-lab workshop. Student groups were tasked to compound different captopril oral mixtures, and their stabilities after storage were analysed. The data were discussed with the students. A mixed-methods approach was adopted to assess the educational intervention, incorporating a pre- and post-survey on meaningful learning, observations, and focus group interviews. **Results:** The results showed that the learning activity was received positively and fostered a meaningful learning experience. The focus groups reported increased confidence, positive effects from a supportive group, reflection, and reduced apprehension. **Conclusion:** This study represents a novel approach to student learning in a pharmaceutics laboratory course, which resulted in an enhanced laboratory learning experience.

Introduction

Pharmaceutics is a pivotal subject in pharmacy education globally. The teaching methods in the subject vary from classroom lectures to practical laboratory courses, as the field includes a wide range of subject areas, covering the scientific and technological aspects of the design and manufacture of dosage forms (Aulton & Taylor, 2021). The US Food and Drug Administration (FDA) defines "*drug compounding*" as the process of combining, mixing, or altering ingredients to create a medication tailored to an individual patient's needs (US Food and Drug Administration, 2022).

The laboratory course on non-sterile manufacturing of medications at the University of Bergen is a one-week course covering various dosage forms, from oral to topical and rectal formulations. Student feedback from previous course evaluations revealed that the laboratory course's time restraints and passing criteria were experienced as stressful and a barrier to learning. This implies that the rigorous focus on quality control and concern for detail required in a compounding course might overshadow the students' motivation for learning. In this pharmaceutics laboratory course, students are provided with complete protocols and proceed to manufacture the product according to instructions. This method results in learning skills such as production techniques, following a set framework in a precise and accurate manner, and mirrors the protocol-focused working routines of the pharmaceutical industry. While such methods and learning outcomes have merit in replicating the routine of the pharmaceutical industry, it is also required that pharmacists possess what has been described as twenty-first-century skills: problem-solving, communication, creativity, and critical thinking (Trilling & Fadel, 2012). These skills are less nurtured in traditional lab teaching, and it is necessary to apply other educational methods and theories to develop these skills.

Problem-based learning (PBL) has been shown to foster critical thinking and collaborative problem-solving among students (Yew & Goh, 2016). Students are given a real-life and contextual problem to solve, which motivates them towards self-directed learning and fills the knowledge gap through collaborative knowledge (Hendriana *et al.*, 2018; Savery & Duffy, 1995).

Complementing PBL, experiential learning theory provides a framework for '*learning by doing*'. It emphasises transforming experience into knowledge (Piaget, 1976; Dewey, 1986; Kolb, 2014; Lewin, 2018;). Experiential learning is defined as "*the process whereby knowledge is created through the transformation of experience. Knowledge results from a combination of grasping and transforming experience*" (Kolb, 2014).

Finally, recognising the importance of self-awareness in cognitive processes and regulating one's thought patterns, metacognition (Downing *et al.*, 2009) is pivotal for achieving deep, enduring, and transferable learning. This is particularly relevant in laboratory settings where students are expected to apply problem-solving strategies effectively (Rickey & Stacy, 2000). Regarding pharmacy education, pharmaceutical compounding skills are becoming essential for solving present and future problems. For example, situations related to medicine shortages, where a particular active pharmaceutical ingredient (API) or excipient is unavailable at the time of compounding. In these cases, knowledge and skills in pharmaceutical compounding must be applied to solve the situation and maintain product delivery. A common example of a paediatric formulation of an extemporaneously prepared mixture is using tablets as a medicated powder to supply the API and Ora-Blend as a vehicle providing taste and conservation. In the pharmaceutics lab course at the University of Bergen, captopril tablets were chosen as the medicated powder for formulating an Ora-Blend-based mixture. The challenge with captopril being unstable when stored at room temperature (Brustugun *et al.*, 2009) was then used to evolve the students' problem-solving skills to find the optimal formulation that would produce the most stable end-product, and thus, practical for the end user, i.e. the patient.

The primary aim of this intervention was to implement problem-based learning methods combined with cognitive reflection to train and assess students' confidence and student agency in the laboratory course. Additionally, it investigated to what extent student-centred teaching methods foster a meaningful learning experience. Captopril is prone to degradation in aqueous solutions at low concentrations, such as in paediatric formulations (Brustugun *et al*., 2009). This makes it an appropriate example for demonstrating drug degradation in a short time, such as a one-week laboratory course.

Methods

Design

This study was conducted in the autumn semester of 2022 in the Pharmaceutics course at the University of Bergen. The class consisted of 22 students in their fourth year of a five-year integrated masters programme in pharmacy. The learning activity was executed as an integrated part of the laboratory course, but the data collection, observation, and focus groups were conducted by the postdoctoral educational researcher within the FREMFARM project to avoid influence and bias.

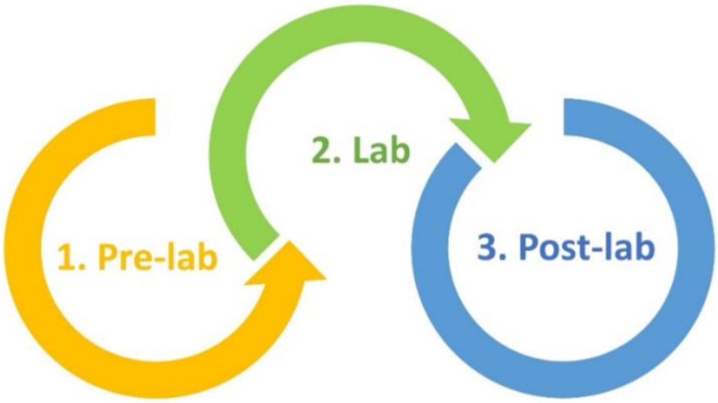
Development of student assignment

Several recipes containing captopril tablets for oral mixture were retrieved (Table I). The formulations have varying shelf lives.

Table I: Stability of various recipes of extemporaneous preparations of captopril mixtures

Formulation	Shelf-life		Reference
	25°C	2-8°C	
Captopril 1 mg/ml in aqueous solution	7 days	26 days	(Kristensen *et al.*, 2008)
Captopril 0.75 mg/ml in Ora-Blend	7 days	14 days	(Allen *et al.*, 1996)
Captopril 1 mg/ml with ascorbic acid	14 days	56 days	(Nahata *et al.*, 1994)
Captopril 1 mg/ml with multiple excipients		12 months	(Brustugun *et al.*, 2009)

The learning activity was designed, implemented, and evaluated by the educators in collaboration with an educational researcher. The outline of the activity is shown in Figure 1.



1. Pre-lab workshop	2. Lab	3. Post-lab workshop
Presentation of problem	Practical work	Results
Group discussion	Group work	Group discussion
Feedback from teacher	Feedback from teacher	Feedback from teacher
Reflective audionote	Reflective audionote	Reflective audionote
		Activity evaluation

Figure 1: Activity outline. The educational intervention is described in three parts: 1. Pre-lab workshop, 2. Lab and 3. Post-lab workshop

Outline of the educational intervention

The activity consists of three parts; 1) Pre-lab workshop, 2) Lab course, and 3) Post-lab workshop. The reflective audionote (RAN) functions as an overreaching part of the intervention. Details on the different parts are outlined below:

Pre-lab workshop

The students were presented with the following assignment:

"*Find a captopril oral mixture formulation, suitable for children, that can be made in a small-scale hospital pharmacy setting, with the longest shelf-life possible.*"'Students were given time to search the relevant literature and discuss their findings in groups of four to five students, followed by teachers' feedback. Finally, each group chose one formulation to make in the laboratory. In addition, a general lecture on the use of HPLC analysis to investigate the stability or degradation of end products was provided. At the end of the pre-lab workshop, each student was asked to record a two-minute audionote reflecting on what they learned in the activity.

Lab course

The complete laboratory course on the manufacture of non-sterile medications at the University of Bergen consists of nine products representing different dosage forms. The new activity was implemented as part of the course as an example of a paediatric oral mixture. The mixture contained captopril 1 mg/ml and was compounded from 25 mg captopril tablets to mimic the manipulation of tablets into a liquid dosage form, resulting in a product suitable for children in terms of strength, dosage, and compliance. The students crushed the tablets, sieved the resulting powder, and mixed it using predetermined formulations. The practical task was done in groups, with each group making different formulations with varying excipients based on the recipes identified in the pre-lab workshop. The teachers were present in the laboratory and guided the students throughout the practical work. Oral feedback was given to individual students continuously, as well as general feedback to the student group as a whole, based on observation and concerns that were revealed to the teachers in the RAN. The following formulations were prepared:

Captopril tablet in purified water (no other excipients)

Captopril tablet in Ora-Blend

Captopril tablet in purified water + ascorbic acid

Ascorbic acid was added as an antioxidant to protect from degradation, as demonstrated in a previous study (Nahata *et al.*, 1994). Samples for quantitation of drug content were collected from the different groups immediately after formulation and after the mixtures had been stored for seven days at room temperature or 4°C. The amount of captopril in the samples was analysed by HPLC (see Appendix A), and the students calculated the concentrations in their samples using the raw data and the standard curve.

The students performed linear regression analysis and used this to calculate the concentration of their samples. From these data, the students compared which formulation was the best in terms of stability, and how formulation affected captopril degradation. Students were again asked to record a two-minute RAN at the end of each day, reflecting on the learning outcome, and the performance in the laboratory.

Post-lab workshop

Results from the HPLC analysis performed on day zero and day seven were presented by each group. The results were then assessed in the classroom and the students could discuss and reflect upon the results of the analysis. The teachers guided the discussion and gave feedback. After the post-lab workshop, the students recorded a final two-minute RAN, reflecting on the activity overall, positive experiences, negative experiences, and the learning outcomes.

Reflective Audionotes (RAN)

Students recorded a total of seven RANs throughout the course. The RAN constitutes a two-minute oral recording where the students reflect on their expectations and experiences. The RANs were recorded as follows: before the start of the laboratory course (pre-lab RAN), for each day of the laboratory course (five days), and after the completion of the laboratory course (post-lab RAN) (Figure 2). Students were prompted to reflect on expectations, preparedness, and negative and positive prospects for the pre-lab RAN. For RANs recorded during the lab course, the recordings were a running commentary of what happened in the course, and the students were prompted to include a specific learning outcome of the day as well as one positive and one negative experience. For the post-lab RAN, students were asked to reflect on the learning experiences of the lab course in general and the specific learning outcome of the captopril compounding assignment. The teachers listened to the pre-lab course RANs before the start of the lab course, gaining insight into the self-reported preparedness and expectations of the students. The teachers listened to the RANs recorded during the lab course, before the beginning of the next day. This made it possible to address any unclarities, concerns, or doubts from the previous day in the lab before starting the new activity. The post-lab RAN particularly, but also the other RANs functioned as a mode of evaluation of the lab exercise.

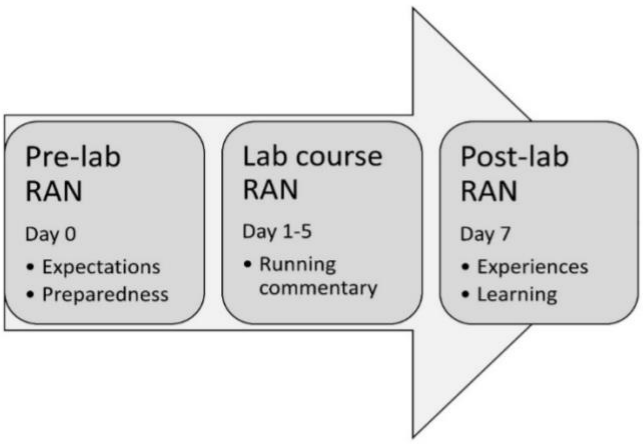


Figure 2: Timeline and content of the reflective audionotes (RAN) throughout the educational intervention

An overview of the educational activity's learning outcomes, method of assessment and level of learning according to Bloom's Taxonomy (Pignato & Birnie, 2014) is presented in Table II.

Table II: Learning outcomes and method of assessment of the laboratory task of compounding a captopril mixture

Learning outcome	Method of assessment	Learning (Bloom's Taxonomy)
Identify the recipe for the captopril mixture	Successful completion of pre-lab workshop, as documented by instructor	Knowledge/application/ analysis
Prepare compounded product	Completion of laboratory task documented by worksheet	Knowledge/application
Evaluate assay results of the compounded product	Group presentation of results in post-lab workshop	Evaluation
Comprehend the concept of degradation and the impact of excipients and temperature on degradation rate	Reflection questions, e.g. based on our analysis, does this product comply with the quality standards?	Comprehension

Collection of research data

Evaluation of the activity was performed through a mixed method approach, combining quantitative and qualitative research methods, using pre-/post survey on meaningful learning in the lab, observation, and focus group interviews.

Survey

To explore students' expectations and experience in the lab course, the Meaningful Learning in the Laboratory Instrument (MLLI) (Galloway & Bretz, 2015) was adapted and translated into Norwegian. This was done by two of the authors independently, and the text was back-translated to ensure accuracy. The students replied to the survey before going to the laboratory (pre-) and after completing the laboratory course (post-). The questionnaire consisted of 30 items. Of these, 16 items were cognitive, eight affective, and six cognitive/affective. Furthermore, 16 were positively worded items, and 14 were negatively worded items. A four-point Likert scale was used, ranging from "*highly disagree*" to "*highly agree*". Students were asked to indicate their agreement with each statement. In the pre-questionnaire, the items were articulated as an expectation, e.g. "*When performing experiments in the laboratory course this semester, I expect (…) to worry about finishing on time*".

In the post-questionnaire, the same items were articulated in the past tense, e.g. "*When I performed experiments in the laboratory course this semester, I (…) worried about finishing on time*". To find if there was a change in the distribution of the answers to the questionnaire between pre and post-lab, a chi-square test of independence was performed for each item. Since the responses were unpaired, the assumption of independence was fulfilled. IBM SPSS Statistics ver 29.0.3 (IBM Corp.) was used for the analysis. The Pearson Chi-square function of the Crosstab analysis tool was used. The test was two-sided, and the level of significance was set at $p < 0.05$.

Classroom and laboratory work observation

The educational researcher employed non-participant observation during group work sessions for both the pre-activity and the captopril activity in the laboratory. The aim was to observe the dynamics of group work by listening to students' conversations and observing their behaviours. Notes taken during these observations were used to prepare for the post-activity focus group interviews, ensuring a comprehensive understanding of the students' collaborative processes and interactions.

Focus group interviews

Two focus group interviews were conducted with students who participated in the lab course during the fall semester of 2022. Group 1 consisted of five students, and Group 2 included six students. Participants were selected through an open invitation announced via the University of Bergen's learning management system, Canvas. The invitation, written in Norwegian, detailed the purpose, date, and time of the focus group discussions. Interested students contacted the educational researcher who had posted the announcement and were assigned to groups based on their availability.

The sessions lasted between 50 to 55 minutes and followed a semi-structured format with guided discussions. The focus groups aimed to explore student perceptions of various teaching activities developed as part of the FREMFARM project and implemented in two courses: FARM321 and FARM295 (the lab course). Particular emphasis was placed on discussing the captopril activity within the lab course.

To ensure rich discussion, the educational researcher prepared for the interviews by conducting non-participant observations during the captopril activity and reviewed RANs recorded by students. The RANs included reflections captured before the activity, during the lab course, and post-lab. This preparation informed the development of the focus group protocol. A detailed list of questions related to the lab course is available in Appendix B.

The interviews were recorded, transcribed, and then translated from Norwegian into English. Before the sessions, participants signed a consent form. Bias was minimised in the focus groups by employing an equitable approach to facilitation. The educational researcher was mindful of potential power dynamics and student vulnerabilities, creating a secure and inclusive space for sharing by setting clear communication guidelines, encouraging diverse participation, and being attentive to non-verbal cues. Furthermore, all student identities were anonymised through coding, ensuring confidentiality and fostering openness in discussions. These measures ensured that students could speak freely without influence from their course instructors or evaluators, promoting authentic and unbiased data collection (Kitzinger, 1995).

Data analysis

Thematic analysis was used to examine students' perceptions of the new teaching methods and their impact on confidence, collaboration, and learning experience. This involved an iterative process of open coding, grouping codes into categories, and generating themes representing the content of these categories. Codes were created by labelling data patterns, grouped in categories, and then linked to form themes. During each cycle, transcripts, codes, categories, and themes were compared, re-coded, and re-categorised as new themes emerged. The educational researcher conducted the coding and reviewed it with the two main educators for peer debriefing.

Ethics

According to the local and national regulations, as this research did not involve patients or personal health information, and it did not require approval from the Regional Ethical Committee. The study was conducted following the Helsinki Declaration, and the General Data Protection Regulation (GDPR) was enforced by registering the project in the University of Bergen system for risk and compliance (RETTE). The university data protection officer ensured that considerations on data protection were sufficient. Students were provided with written and oral information about the study and signed an informed consent form before participating in the study. Furthermore, all participants were informed that data would be treated anonymously and confidentially and that they could withdraw from the study without any consequences.

Results

Findings from survey

The outcomes of the survey on meaningful learning in the laboratory were not specific to the captopril assignment but based on the overall expectations and experiences from the laboratory course. The number of respondents was N=22 (response rate: 100%) and N=19 (86%), pre-and post-questionnaire, respectively. Table III shows the results of the pre-and post-survey, sorted by item and increasing *p*-value. A total of six items displayed a significant change between pre-and post-survey ($p < 0.05$), whereas another seven items showed a trending shift ($p < 0.20$). The remaining items showed no significant change. The items with significant change in distribution were cognitive, affective, or a combination of both categories. In general, the changes pointed to a more positive learning experience during the laboratory course than anticipated.

Table III: Results of the surveys (Galloway & Bretz, 2015)

Item	*p*-value	Cat.		Highly disagree	Disagree	Agree	Highly agree
To be nervous when handling chemicals	0.001	A^-	Pre	1	5	12	4
			Post	3	14	2	0
To be confused about what my data mean	0.004	C^-	Pre	0	8	8	6
			Post	2	15	2	0
The procedures to be simple to do	0.008	C^-	Pre	2	16	3	1
			Post	0	7	12	0
To consider if my results make sense	0.014	C^+	Pre	0	0	20	2
			Post	0	0	11	8
To be confused about the underlying concepts	0.021	C^-	Pre	0	7	13	2
			Post	0	14	5	0
To worry about the quality of my results	0.021	C/A^-	Pre	0	2	17	3
			Post	0	9	9	1
To focus on procedures, not concepts	0.067	C^-	Pre	0	13	8	1

Item	*p*-value	Cat.		Highly disagree	Disagree	Agree	Highly agree
			Post	0	5	13	0
To be confused about how the instruments work	0.085	C⁻	Pre	0	4	15	3
			Post	2	7	10	0
To feel unsure about the purpose of the procedures	0.093	C/A⁻	Pre	2	13	6	1
			Post	6	12	1	0
To use my observations to understand the behaviour of atoms and molecules	0.119	C⁺	Pre	0	3	17	2
			Post	0	7	12	0
To think about basic chemistry	0.147	C⁺	Pre	0	3	15	4
			Post	0	3	16	0
To make decisions about what data to collect	0.160	C⁺	Pre	0	4	16	1
			Post	1	2	11	5
To worry about finishing on time	0.177	A⁻	Pre	0	0	15	7
			Post	0	0	9	10
To be intrigued by the instruments involved in compounding	0.276	C/A⁺	Pre	1	2	16	3
			Post	0	3	15	0
To feel disorganized	0.286	C/A⁻	Pre	0	7	13	2
			Post	1	9	9	0
To feel intimidated	0.323	A⁻	Pre	0	1	10	11
			Post	0	3	10	6
To interpret my data beyond only doing calculations	0.327	C⁺	Pre	0	4	15	3
			Post	0	1	13	5
To be confident when using equipment	0.330	A⁺	Pre	0	2	18	2
			Post	0	5	13	1
To learn critical thinking skills	0.403	C⁺	Pre	0	2	18	2
			Post	0	0	17	2
To learn compounding that will be useful in my life	0.435	C/A⁺	Pre	0	0	11	11
			Post	1	1	7	10
To experience moments of insight	0.438	C⁺	Pre	0	0	7	15
			Post	0	0	4	15
To make mistakes and try again	0.476	C⁺	Pre	0	0	14	8
			Post	0	0	10	9
To be excited to do compounding	0.483	A⁺	Pre	1	0	16	5
			Post	0	1	12	6
To "get stuck" but keep trying	0.491	C⁺	Pre	0	1	14	7
			Post	0	1	15	3
To worry about getting good results	0.532	C/A⁻	Pre	0	0	7	14
			Post	0	1	7	11
To be nervous about making mistakes	0.550	A⁻	Pre	0	1	6	15
			Post	0	0	7	12
To be frustrated	0.569	A⁻	Pre	0	2	11	9
			Post	0	3	11	5
To develop confidence in the laboratory	0.571	A⁺	Pre	0	2	15	5
			Post	0	2	10	7
To think about theory and knowledge I already know	0.808	C⁺	Pre	0	4	13	5
			Post	0	3	13	3
To learn problem-solving skills	0.821	C⁺	Pre	1	1	16	4
			Post	0	1	14	4

N= 22 (Pre-survey). N=19 (post-survey). The table lists the items sorted by increasing p-value. Significant changes ($p < 0.05$) from pre to post are marked in dark grey. The trending shift from pre to post ($p < 0.20$) is shown in light grey. The item classifications based on meaningful learning (Cat.) are: C=Cognitive; A=Affective, C/A=Cognitive/Affective, as well as how the item affects meaningful learning (+ = positive contribution to meaningful; - = hinders meaningful learning). These classifications are the same for both the pre- and post.

For example, the item "*to be nervous when handling chemicals*" displayed a significant change, with more students disagreeing or highly disagreeing in the post-survey. This could be interpreted as students developing confidence or security in handling potentially hazardous ingredients. On the other hand, for the item "*to develop confidence in the laboratory*", the majority of students already present a sense of high confidence in the laboratory setting in the pre-survey, and there is no change from pre to post, indicating that neither the educational intervention nor the lab course as a whole, affected the students' confidence in the laboratory. Furthermore, the items "*the procedures to be simple to do*", and "*to consider if my results make sense*", both display a significant change from pre- to post, where student opinion shifts towards agree and highly agree. Both items support that the students gain an overview throughout the laboratory course.

Additionally, the item "*to be confused about the underlying concepts*" shows a significant shift from agree to disagree. The item "*to focus on procedures not concepts*" shows a non-significant trend towards more agreement from pre- to post-survey (p = 0.067). This is classified as a negative influence on learning, but in this setting, it can be interpreted as positive. To follow a certain procedure is detrimental to obtaining the necessary quality of the end-product in pharmaceutical compounding and is thus one of the desired learning outcomes of the course. In that respect, a trend towards agreeing in the post may signify that students have absorbed this learning outcome after the course.

Findings from focus group interviews

Reduction of stress and apprehension

All the students who participated in the focus groups shared that they had experienced apprehension before the laboratory course. They related this to many factors, including rumours and comments from previous students about difficulties and challenges in the laboratory course. However, all the interviewed students expressed that the pre-course activities (Figure 1) allowed them to be better prepared and more confident. As one student mentioned: "*No stress, no panic*". The clear expectations and preparation in groups helped them approach the lab course with a calm and composed mindset. Another student added, "*Well, it went much better than expected*", and highlighted the contrast between their prior apprehension and their pleasant learning experience.

Supportive group environment

The focus group participants praised the benefits of working collaboratively in groups. The group dynamic provided a supportive learning environment where students could rely on one another for assistance. As one student explained, "*It's always nice to work in a group, especially when you're unsure. At the beginning, I don't think I fully understood what we were supposed to do, but discussing with peers helped me find out and understand better".* This mutual support encouraged experimentation and allowed them to learn from each other. The sense of companionship also helped dispel any fears of making errors. Moreover, group discussions provided valuable insights, as one student shared: "*You get tips from the others on how to do things".* Participants explained that starting their laboratory course with a group activity also prepared them for working individually. The group environment promoted a positive and encouraging atmosphere.

Cognitive reflection and learning from mistakes

The use of the RAN combined with the PBL approach fostered a culture of reflection and learning from mistakes. The students exhibited a growth mindset, analysing their errors and planning for improvement. One student mentioned, *"So I knew what went wrong, and I planned that next time I can do things here or there better".* This reflective approach empowered them to embrace challenges and see them as opportunities for learning. Several students noted that having a structured reflective assignment, in addition to a clear framework, assisted them in using the RAN as a method to structure their thoughts after a day in the lab, consider what they had learned and plan for what was ahead in the lab course. This follows the Kolb experiential learning theory (Kolb, 2014).

Impact on confidence and perception

The PBL approach improved the students' confidence and perception of the lab course. Despite initial concerns, the students' confidence grew steadily as they engaged in active learning and received support from their peers and teachers. As one student revealed, "*I started to worry about that course since the summer holidays. But now I am telling you that it was completely unnecessary worry".* Participants confirmed that the transformative experience dispelled their apprehension and reshaped their perception of the course. They now saw it as a positive and rewarding learning journey rather than a daunting challenge.

Discussion

In this study, the results of a small-scale pilot intervention focusing on improving the learning experience of the pharmaceutics lab are reported. A triangulation approach, collecting both quantitative data using a pre-and post-lab survey and qualitative data through focus groups, was adopted. Despite the limited sample size, making it challenging to generalise to a larger student group, the results from the survey combined with the in-depth qualitative findings from the focus group interviews strengthen the transferability of the study results. In addition, the results from the survey and the focus groups aligned and imply that students gained confidence and student agency during the laboratory course. The results can also be interpreted as enhanced learning outcomes outside of the specific lab experiments, gaining an overarching understanding of pharmaceutical compounding. In this setting, the students have thus been provided with 21st-century skills, such as collaboration and critical thinking. Additionally, the students report that the activity fostered a meaningful learning experience in pharmaceutical compounding.

A recent literature review on the introduction of PBL in undergraduate chemistry laboratories concludes that PBL positively impacted learning (Varadarajan & Ladage, 2024). It highlights the importance of creating contextual problems from real life to harvest the full learning potential. This corresponds to the findings in this study, specifically from the RAN, where students reflect upon how the exercise assisted them in bridging the gap between theory and practice. In the following, this will be discussed in more detail, as well as how the study can provide valuable insights for future course development and research.

Cognitive and affective effects on learning

The apprehension the students expressed, both in the pre-survey, the pre-lab RAN, and the focus groups, shifted towards higher levels of confidence and mastering of skills in the data collected post-lab course. This demonstrates an important positive impact of the new approach and highlights how targeting the affective side can foster a meaningful learning experience. While the students still expressed that they found the lab exercises stressful due to the pressure of getting assignments approved in a limited time frame, the focus group interviews also revealed that they reported it as enjoyable as well as useful. In line with other findings (Van Dinther *et al.*, 2011), the data presented here implies that the new learning activities have strengthened their self-efficacy or their belief in their capacity to complete the assignment. It also made them more comfortable in handling the stress of the time pressure. Thus, despite the intensity of the lab course, students mention enjoying the practical tasks and learning a lot also thanks to the collaboration and supportive group environment in the laboratory. Studies have shown that learners with higher confidence are more willing to learn, challenge themselves, and exhibit better resilience in the face of difficult transitions (Stankov *et al.*, 2012). Confidence has been identified as the number one predictor of academic achievement. Educators face the challenge of balancing the cognitive and affective aspects of learning, for example giving structured guidance and formative feedback, versus encouraging students to explore and problem-solve independently. In the case presented here, the use of the reflective tool (RAN) provided educators with insights into students' expectations, concerns, and learning processes as they took place rather than retrospectively. This understanding allowed them to identify students' needs and provide the appropriate guidance and support, thereby enhancing the overall learning experience. A previous study has investigated both students' and staff's perceptions of students' learning in teaching laboratories (George-Williams *et al.*, 2019), also using the MLLI survey (Galloway & Bretz, 2015) as in this project. That study concluded that there was a discrepancy between the expectations of the staff and the students regarding learning, and if those discrepancies were not addressed, it would cause frustration for both groups (George-Williams *et al.*, 2019).

In the present study, the teachers' perspective on learning was not specifically investigated, but the project itself was designed from the educators' preconception that the students had challenges in transferring their theoretical knowledge into practical skills and problem-solving. Throughout the learning activity, students reported in their RAN that they found the meta-conversation about learning outcomes useful and relieved their apprehension, and this was confirmed in the focus group interviews. Thus, the results presented here demonstrate that both the students' and the educators' expectations were better matched and understood through the use of the RAN.

Metacognitive experiential learning

This project aimed to provide the students with a meaningful learning experience. Traditional education often fosters a sense of internalised oppression and a lack of authentic learning (Freire *et al.*, 2014). In contrast to this, the present study shows that by combining PBL with a reflective experiential learning tool (RAN) in a pharmaceutical laboratory course, students were able to understand the ways they learn from experience and themselves as learners and improve their learning. This metacognitive experiential learning approach assisted students in making sense of their learning and allowed them to reflect on the challenges they faced (Downing *et al.*, 2009). As a result, they gained greater confidence and acquired the necessary mastery in the laboratory setting. When students participate in the construction of knowledge, they become active participants in teaching and learning processes rather than passive receivers of knowledge (Klemenčič, 2020).

The lab exercise developed at the pharmaceutics course at the University of Bergen wanted to address this, by giving students the chance to search the literature independently, decide on which formulation to use, and compound a mixture by themselves during the laboratory course. This resulted in the involvement of the students in the decisions about the design of the learning process, further helping them navigate the laboratory environment independently and be empowered as learners. In essence, it fostered a sense of student agency along with refined skills in analytical thinking and problem-solving. This aligns with a previous survey, which investigated students' perceptions of when they experienced meaningful learning (Andrews *et al.*, 2023). In the survey of Andrews and coworkers, students said that they found lectures useful for introducing new topics or information, but not for profound and meaningful learning, as it doesn't pose opportunities for active engagement, as PBL or group-based learning does.

Limitations

When collecting the data from the survey, an online form that did not include any identifying variable was used. Consequently, it would have been valuable to be able to pair the pre- and post-survey data to see the individual changes. Nevertheless, it was possible to extract significant changes in key statements. The student test group was relatively small (22 students), but on the other hand, it represents the student group as a whole, as the number of students in one class of pharmaceutics at the University of Bergen typically is between 20–25. The educational intervention was performed as an integrated part of a mandatory course. Although the participation in the data collection was voluntary, being subjected to the intervention was inescapable for the students. In performing research on students, the teachers were aware of the challenge of power dynamics in the student-teacher relationship.

The observation data and focus group interviews were therefore performed by an educational researcher to avoid bias. All the authors were part of the analysis of the research data to increase the validity. The primary analysis and coding of the focus group interview transcripts was performed by the educational researcher in collaboration with two of the educators. The results from the survey were discussed with the whole group of educators. The group of educators involved in the study had varying backgrounds, ranging from pharmacy to cell biology and physical chemistry. The results from this study cannot demonstrate a quantitative effect on exam scores or knowledge, but on the other hand, the skills gained from the intervention are challenging to assess using traditional exam settings.

Conclusion

In this study, the use of PBL and reflection in a laboratory setting was designed to foster a meaningful learning environment. The restructuring of a laboratory activity from making the students passively follow a given recipe to enforcing student agency and active planning and participation has supported the students' problem-solving- and critical thinking skills. Combined with the use of the RAN throughout the educational activity, the students display increased confidence and student agency. Although this study was performed in a pharmaceutics course, the methods applied are valid for any laboratory or simulation-type setting concerning meaningful learning aspects.

As this was a small-scale study, further investigations could give even better indications for which interventions give the best learning environment. Nevertheless, the contribution and demonstration of the use of PBL and reflection in a laboratory setting represent a novel approach to enhancing student learning by targeting the affective as well as the cognitive aspects of the learning environment. Ultimately, this enables adaptable learners who are well-prepared to thrive in complex environments and equipped to face the challenges of the future.

Conflict of interest

The authors have no competing interests to declare.

Source of funding

This learning activity was designed, implemented, and evaluated as a continuation of the FREMFARM project (AKTIV-2019/10201), funded by the Norwegian Directorate for Higher Education and Skills and The Norwegian Foundation for Pharmacy Practice Research.

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